*http://smap.jpl.nasa.gov*

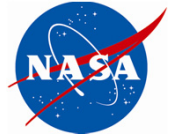# Dynamic Modeling of the SMAP Spinning Flexible Instrument
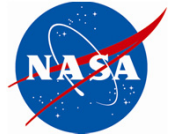
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*July 24, 2012*

NASA SLaMS Young Professionals' Workshop

*NASA JSC, July 2012*

# Overview: SMAP Project

➢ **The Soil-Moisture Active/Passive (SMAP) mission will provide global measurements of the soil moisture and its freeze/thaw state**

➢ **The accuracy, resolution, and global coverage of SMAP soil moisture and freeze/thaw measurements help us :**
  ❖ Quantify key parameters in the global hydrologic and carbon cycles
  ❖ Extend weather/climate forecast capabilities
  ❖ Enhance understanding of processes that link the water, energy and carbon cycles

➢ **Launch is planned for 2014**



http://smap.jpl.nasa.gov/mission/
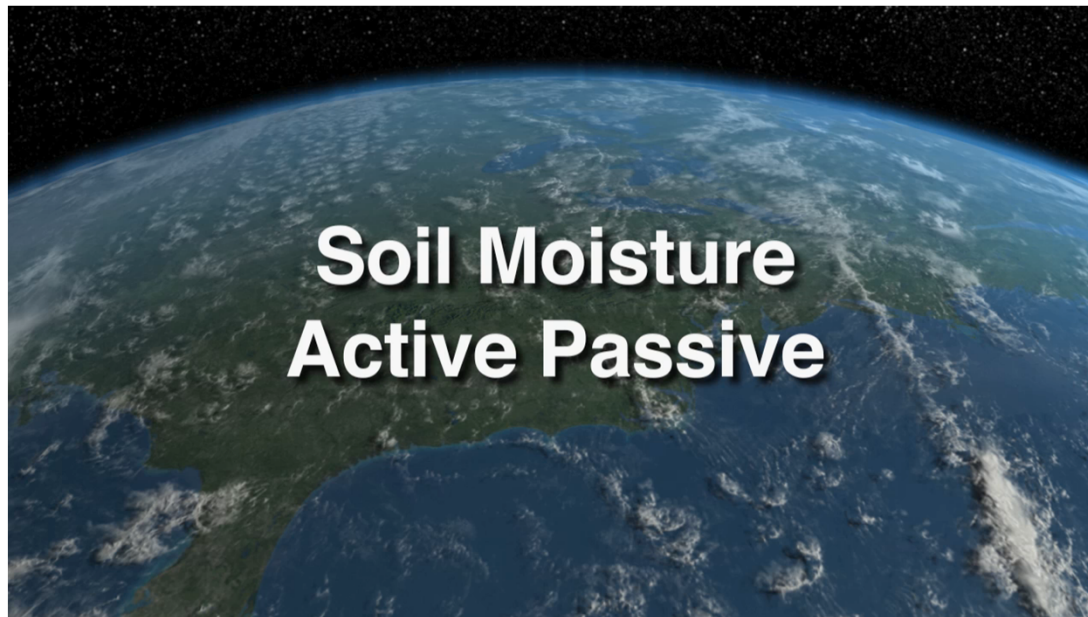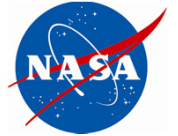
# Overview: SMAP Dynamic Modeling

## Key Characteristics

➢ **Balancing:** the goal is to null out any mass imbalance by using passi
launch

- There will be no active on-orbit balancing mechanism
- Mass imbalance comes from two sources: (a) Spun CM offset, and
(POI)

➢ **Momentum Compensation:** the Control system maintains a zero ne
by nulling the spun momentum using Reaction Wheels

➢ **Frequency Separation:** Structural modes are way above the control
Control Structure Interactions (CSI)
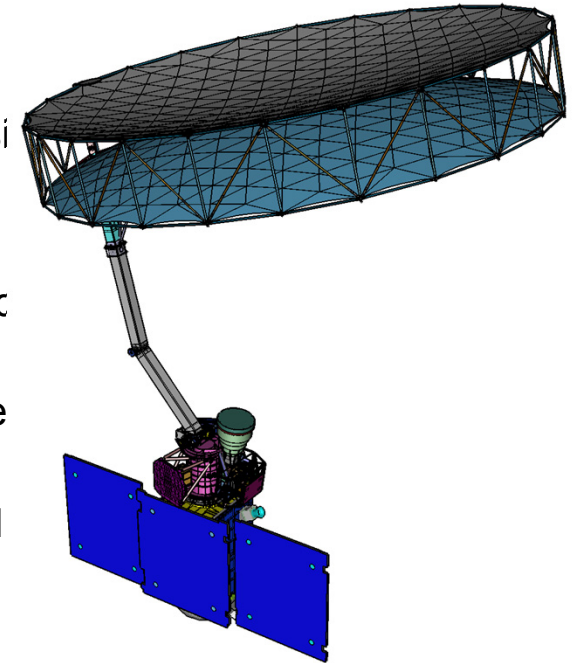
## Dynamic Model Applications

➢ **Pointing Error Performance:** Dynamic models are used to quantify the beam boresight pointing errors due to dynamic sources, and compare against the project pointing requirements

➢ **Control Design Verification:** Used as nonlinear plant models for the time domain control analysis and verification of the stability margins against the project requirements
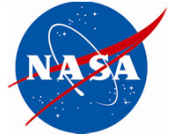
# Overview: ADAMS Multi-Body Models

## CMS model:

➢ High fidelity normal mode model based on Component Mode Synthesis (CMS) formulation
➢ Many elastic DOFs: depending on the number of component modes included
➢ Includes Reflector flexibility and its mesh preload
➢ Closest to the truth in in terms of SMAP dynamics and spin structure interactions
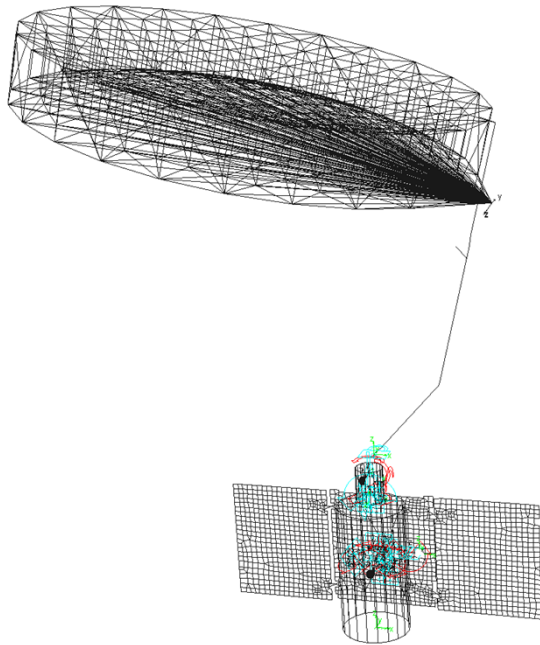


## Discrete model:

➢ Low Fidelity Lumped Mass/Stiffness model
➢ With few elastic DOFs
➢ Rigid Reflector
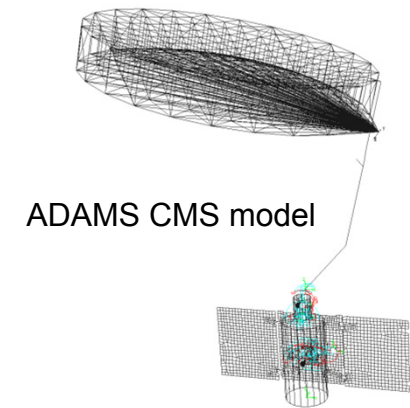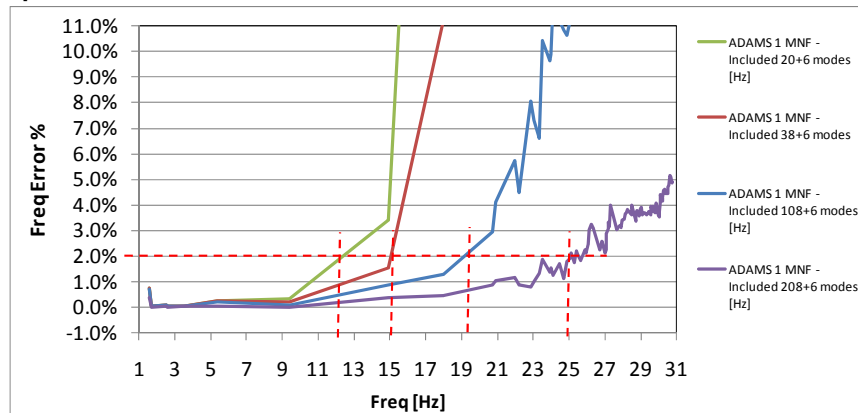➢ Much faster to simulate, hence suitable for the Monte-Carlo Analysis
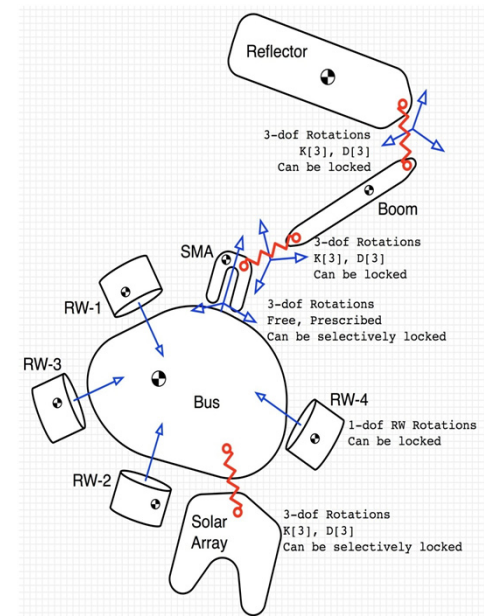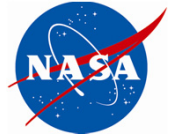
# ADAMS CMS Model Development

## Modal Truncation Study:

- Increased the number of component modes in the CMS model until ADAMS System Eigen-frequencies match NASTRAN within a desired accuracy in the freq range of interest
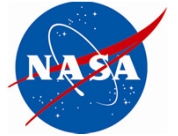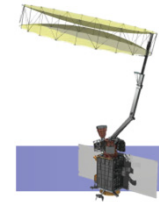


ADAMS CMS model

## Splitting Large Components into Multiple Sub-Components:

- The CMS formulation uses linear modal superposition, and for that it assumes small flexible body deformations
- Splitting large components into multiple bodies increases the CMS accuracy, since the nonlinear behavior of large deformations, is captured using a piecewise linear system
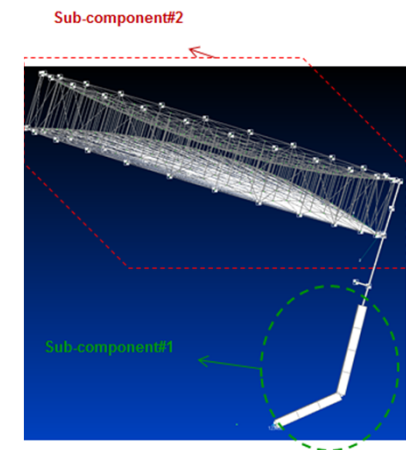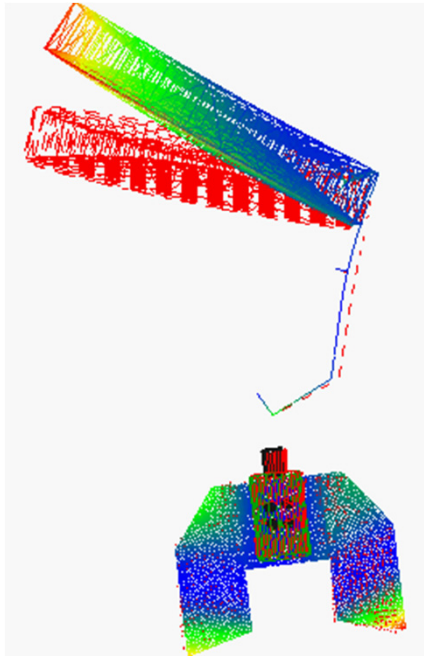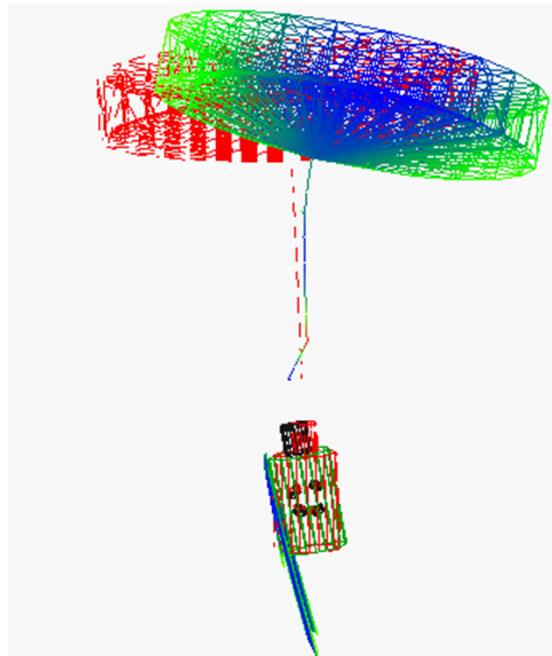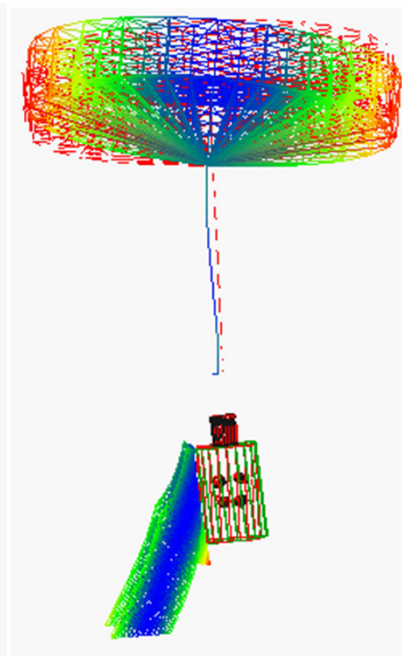
# ADAMS Observatory Mode Shapes

**1st antenna nodding about Y-axis**     **1st antenna tip-tilt about X-axis**     **1st Solar Array Bending mode**     **1st Reflector Mesh Mode**
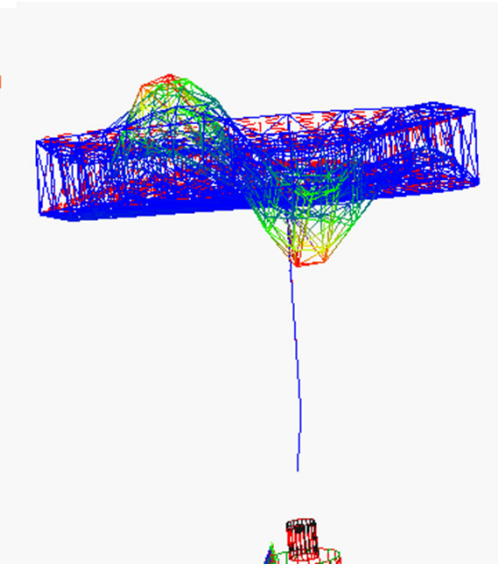


➢ **CMS Model Verification Steps:**

At non-spinning state (0 rpm), NASTRAN model is our truth

Compare the following ADAMS dynamic properties against NASTRAN:

- Observatory mass properties
- Observatory eigen-frequencies of the linearized model
- Nonlinear deformations due to a static load
- Linear Transfer Functions (frequency domain)

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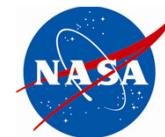
# Clock Angle Effects

As the instrument goes around the clock the system configuration changes, and as a result, we observe:

- Changes in system mass props

- Changes in the system eigen frequencies

- Changes in the System FRFs

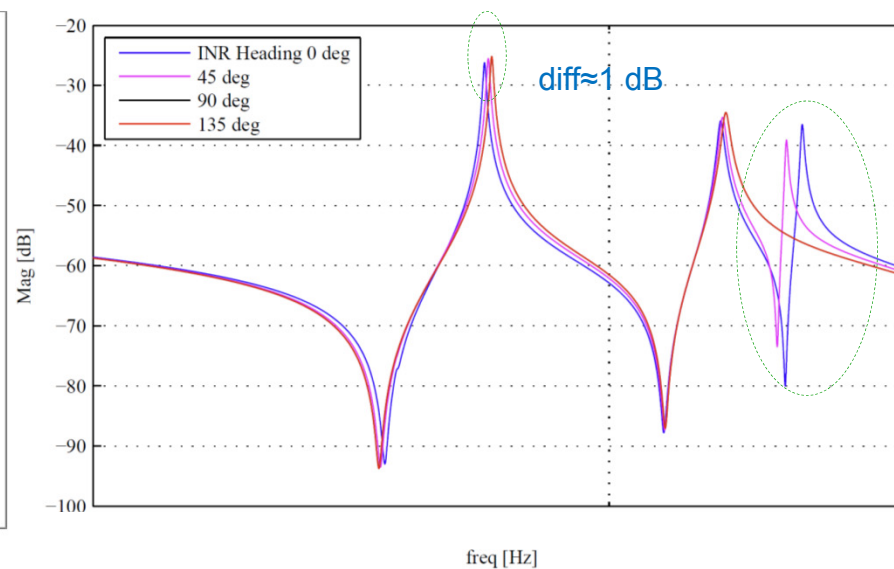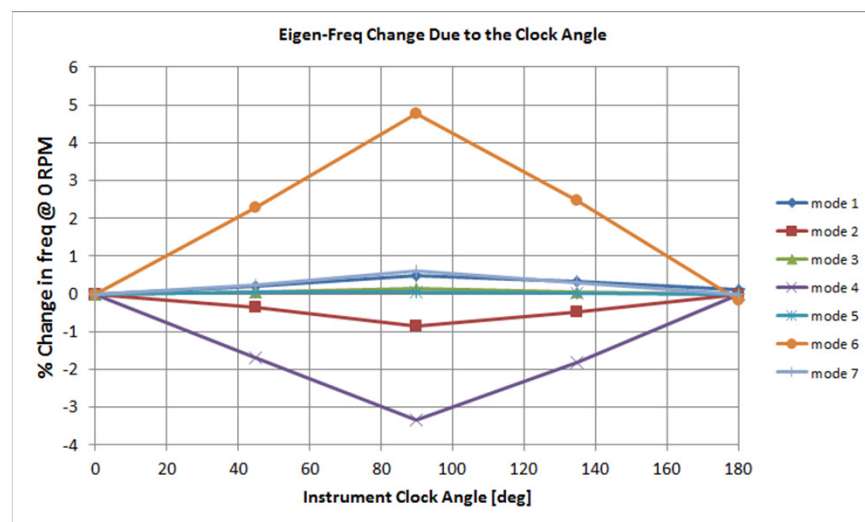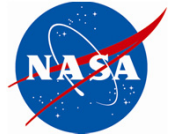# Time Varying Nature of the Problem (1 of 2)

**Poles & Zeros change as a function of instrument clock angle while spinning**
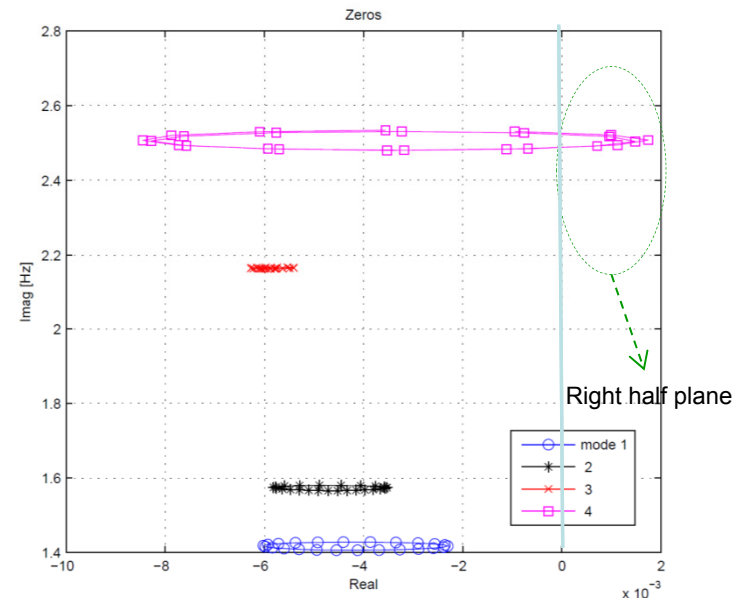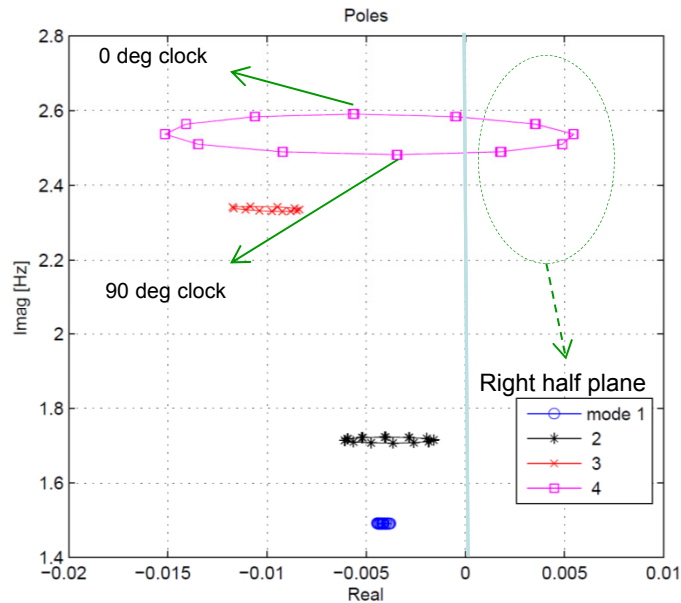


- System poles and zeros in the complex plane (Root -Locus) move on ellipse-type shapes as a function of clock angle
- For each mode, the pole/zero ellipse repeat on itself every 180 deg (clock angle)
- For some clock angles the system poles/zeros may go to the right-half complex plane

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# Time Varying Nature of the Problem (2 of 2)

- The system at the spinning state is a Time Varying problem, and the Linear Time Invariant (LTI) stability assumptions do not hold.
  - System has significant time-varying periodic features → system stability can NOT be assessed using a "standard" LTI transfer function approach
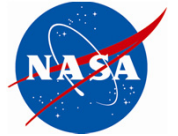  - The poles/zeros of the linearized model may instantaneously go to the right half plane, but that alone is not an indication of instability of the system

- For a *time varying periodic* system like this, *Floquet* analysis is the right approach to assess stability

- Final confirmation of system robustness and stability performance should be done using nonlinear time domain simulations
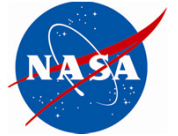
# Spin Rate Effects on the System Eigen-freq

## Dependency on the Spin rate:

➢ Centrifugal and gyroscopic effects, cause system natural frequencies to change as a function of spin rate (spin stiffening/softening effects)

- The dependency is minimal if the spin freq is way below the natural frequencies

**Modal Freq Change Vs Spin Rate**

Legend:
- 1st mode
- 2nd mode
- 3rd mode
- 4th mode
- 5th mode

Y-axis: % of change (from -4.0 to 4.0)
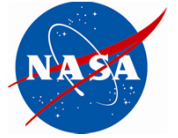X-axis: Spin Rate [rpm] (0 to 30)
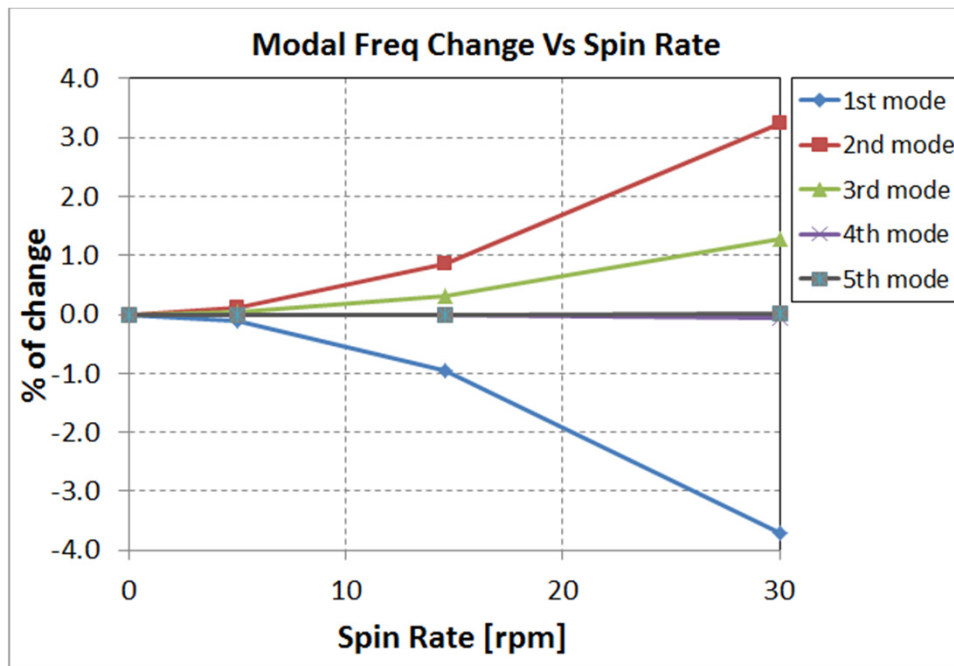
**Computing the freq and damping from a complex modal analysis:**

$$\Omega_i = \alpha_i + j\beta_i \quad [Hz]$$

$$f_i = \sqrt{\left(\alpha_i^2 + \beta_i^2\right)} \quad [Hz]$$

$$\varsigma_i = \cos(\tan^{-1}(\beta_i / \alpha_i))$$

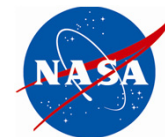# Damping Implementation in the CMS Model (1 of 2)

**Goal:**
➤ Projects normally desire to enforce a damping policy at the observatory (system) level. To that end, in a CMS model one need to define the damping values at the component level in order to enforce a desired system level damping

**Challenges:**
➤ User can specify the modal damping for the component modes. However, once the components get synthesized with the rest of the observatory model, the observatory (system) modal damping is going to be different

➤ Moreover, component modes can couple, making it impossible to obtain exactly the desired modal damping for all system modes
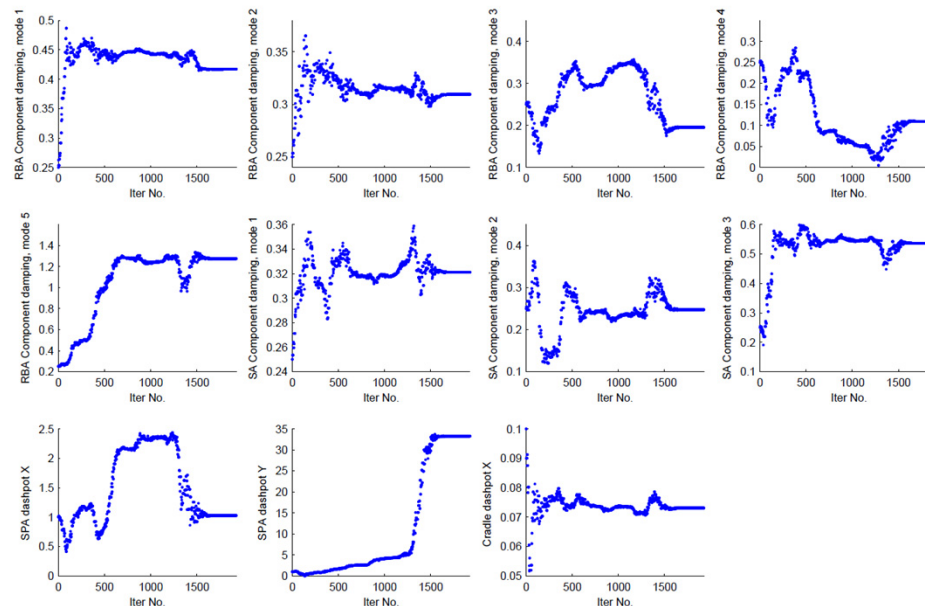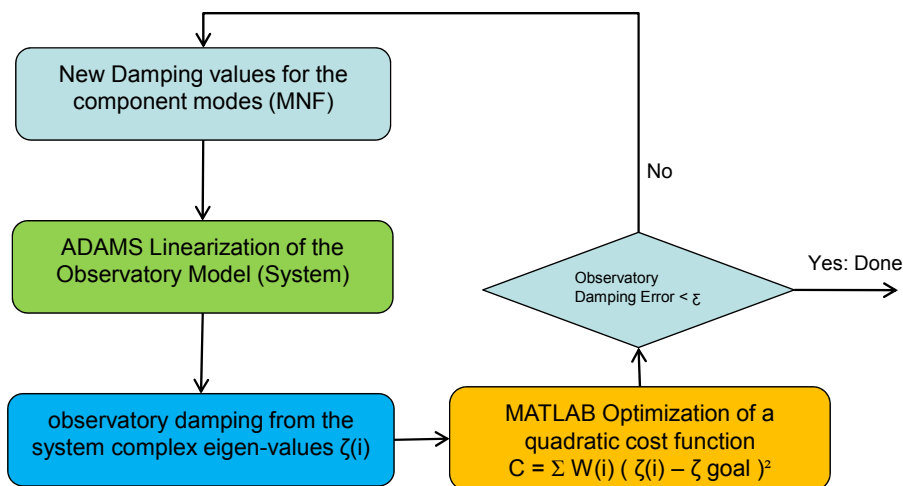
**Approach:**
➤ An optimization program was developed in MATLAB in order to tune the observatory (system) modal damping by iteratively changing the component modal damping values

# Damping Implementation in the CMS Model (2 of 2)

**The optimization algorithm is implemented in MATLAB, having ADAMS in the loop**



> The first step in this process is the ***Component Mode Sorting***, which is the process of identifying the component modes that dominantly affect the primary modes of the system. We only need to optimize those dominant component modes and not all of them.

> It is recommended to over-damp (> 10 %) the high freq residual component modes, which effectively means ignore the inertia effects but keep the compliance

> Random search optimization techniques are more suitable to handle this problem with a discontinuous error surface
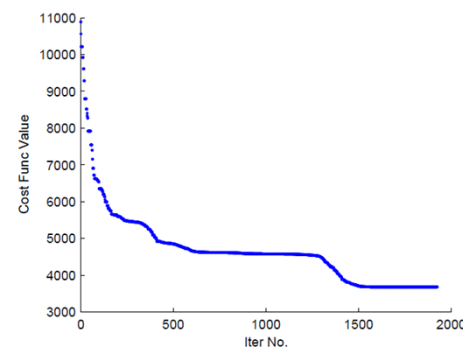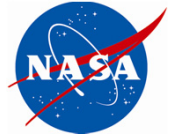
# Summary and Conclusions

- ➢ Dynamic model development in ADAMS for the SMAP project explained

  - The main objective of the dynamic models are for pointing error assessment, and the control/stability margin requirement verifications

- ➢ In the CMS formulation, splitting large components into multiple bodies increases the model accuracy, since the nonlinear behavior of large deformations, is captured using a piecewise linear system

- ➢ Spin rate effects and instrument heading angle (clock angle) effects on the system dynamics should be considered and quantified

- ➢ It was shown that the system at the spinning state is a Time Varying problem, and the Linear Time Invariant (LTI) stability assumptions do not hold.

  - For a time varying periodic system like this, Floquet analysis is the right approach to assess stability

- ➢ Damping Implementation in the CMS Model to enforce a system level requirement could be a challenging task

  - Proposed an optimization technique to tune the component mode damping in order to achieve a desired system modal damping